

# Fast pyrolysis of biomass: work in progress at ENEL Produzione

IEA - Clean Coal Sciences Agreement

23<sup>rd</sup> Meeting

Pisa, October, 25<sup>th</sup>, 2002

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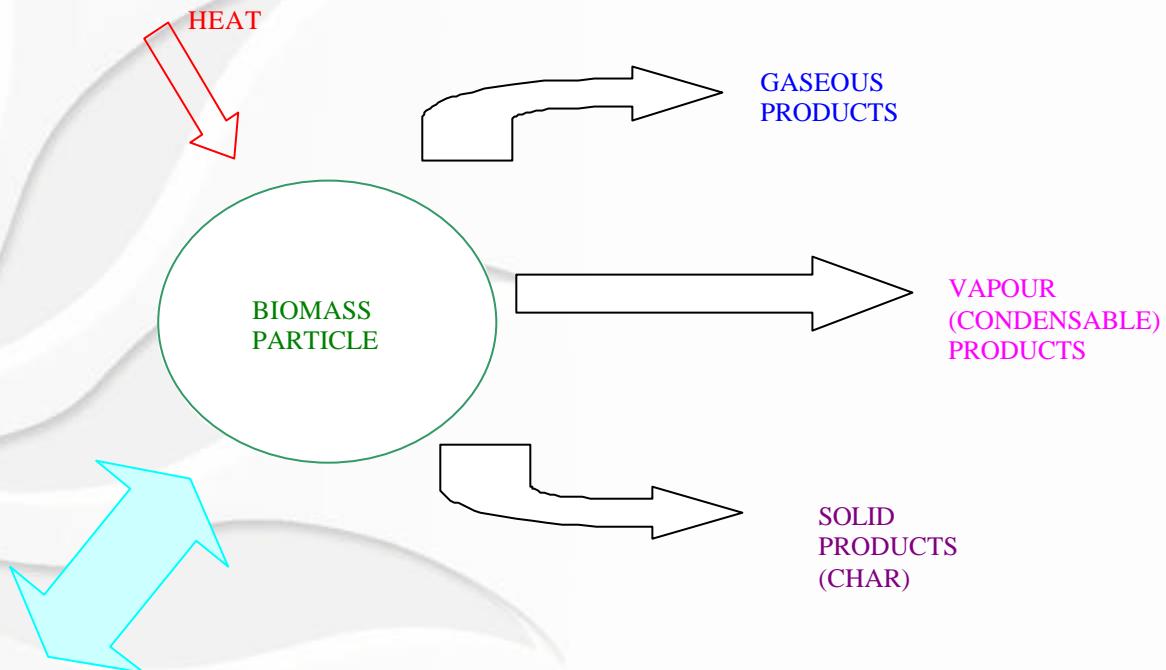


# Pyrolysis of Biomass

- The thermal decomposition of biomass material into a non-oxidizing atmosphere, acting a very quick heat-up.
- The main advantage would be the availability of a liquid fuel, easy to store and to transport, which could help to overcome the difficulties deriving from the low bulk density of biomass.



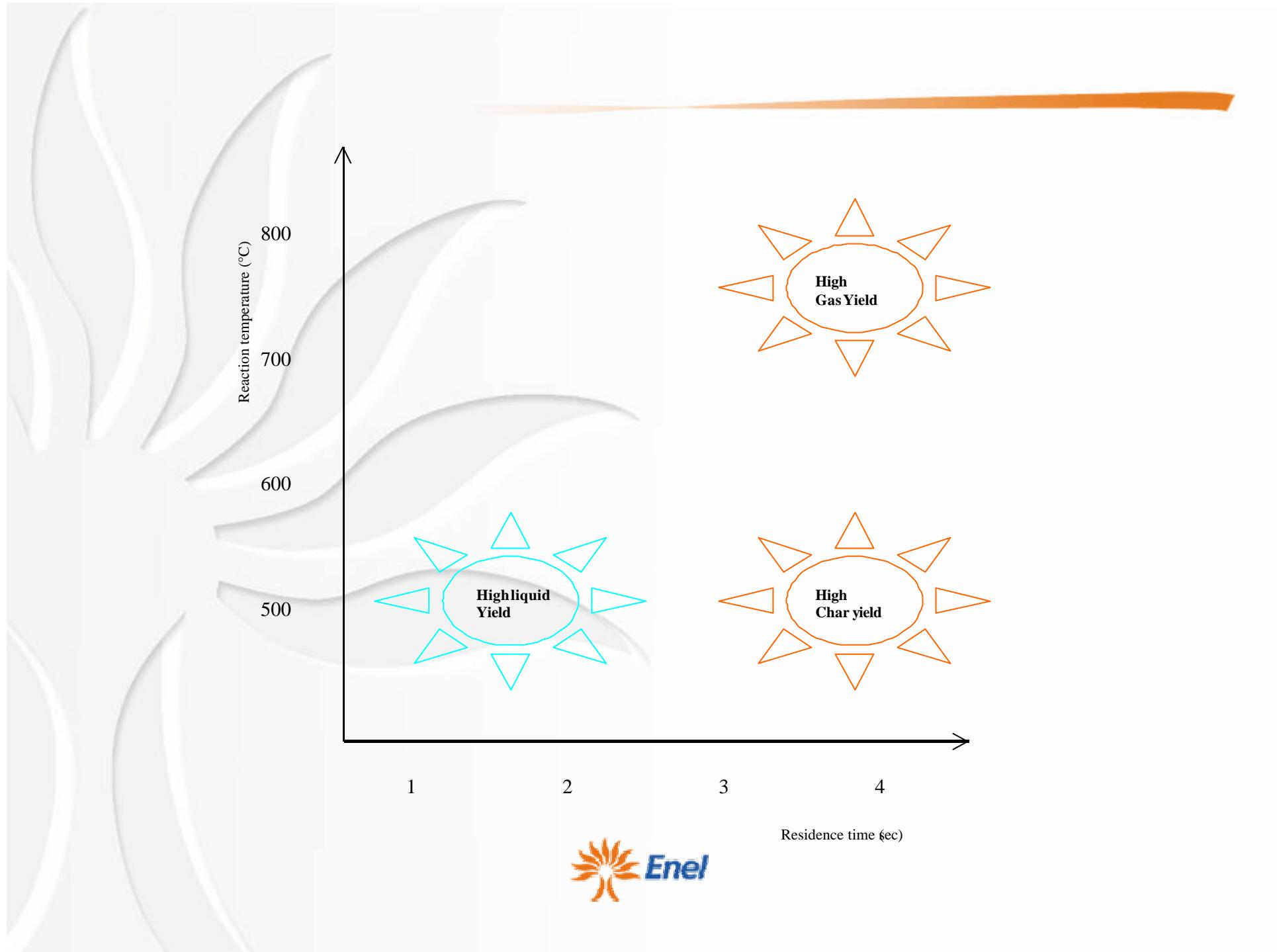
# Pyrolysis of a biomass particle



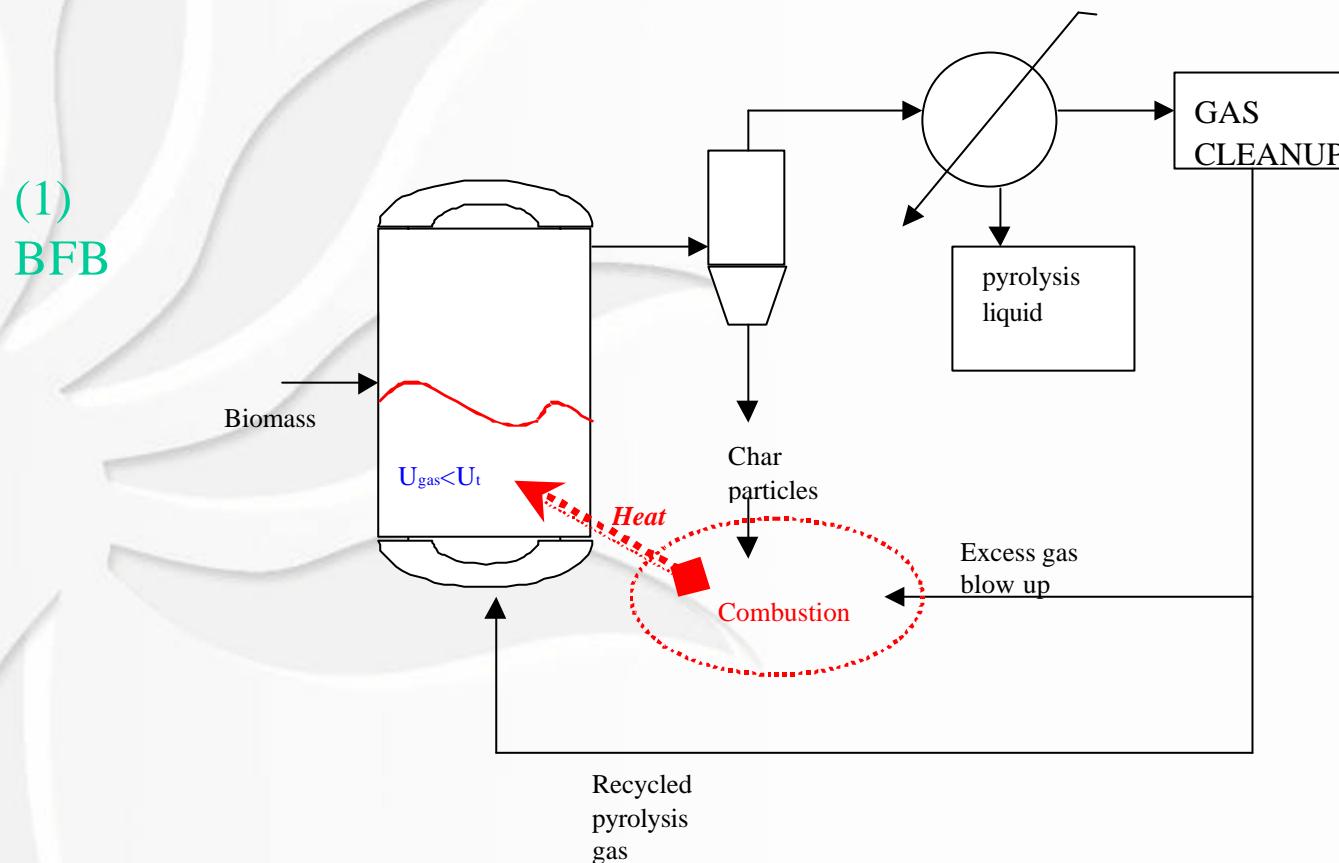
# Fast Pyrolysis process

- Particles are heated up in few seconds
- Equilibrium composition must not be reached to maximize the liquid yield:
  - There is an optimum residence time for the gas + vapour mixture of 1 or 2 seconds inside the reactor, and
  - There is an “optimum” reaction temperature

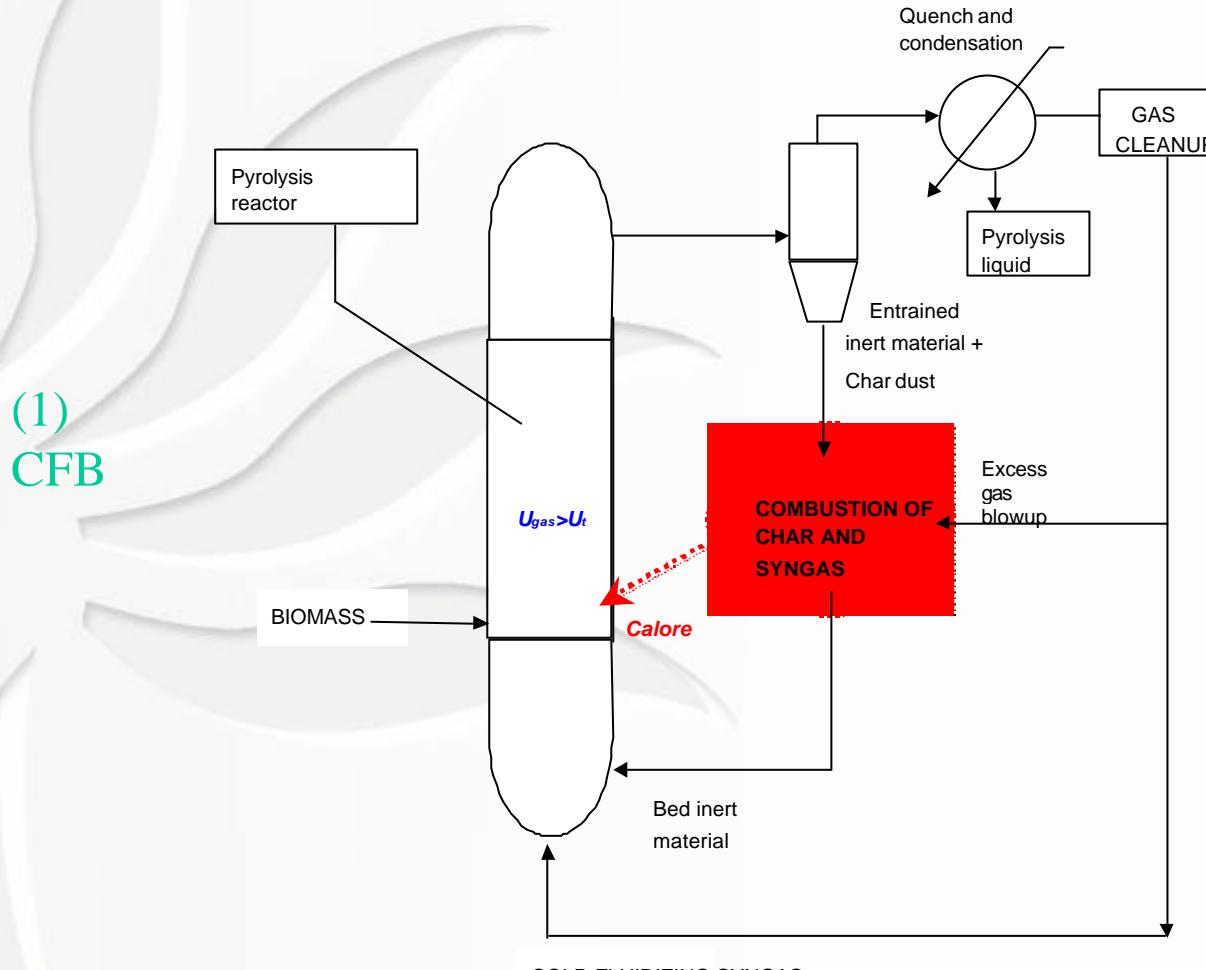




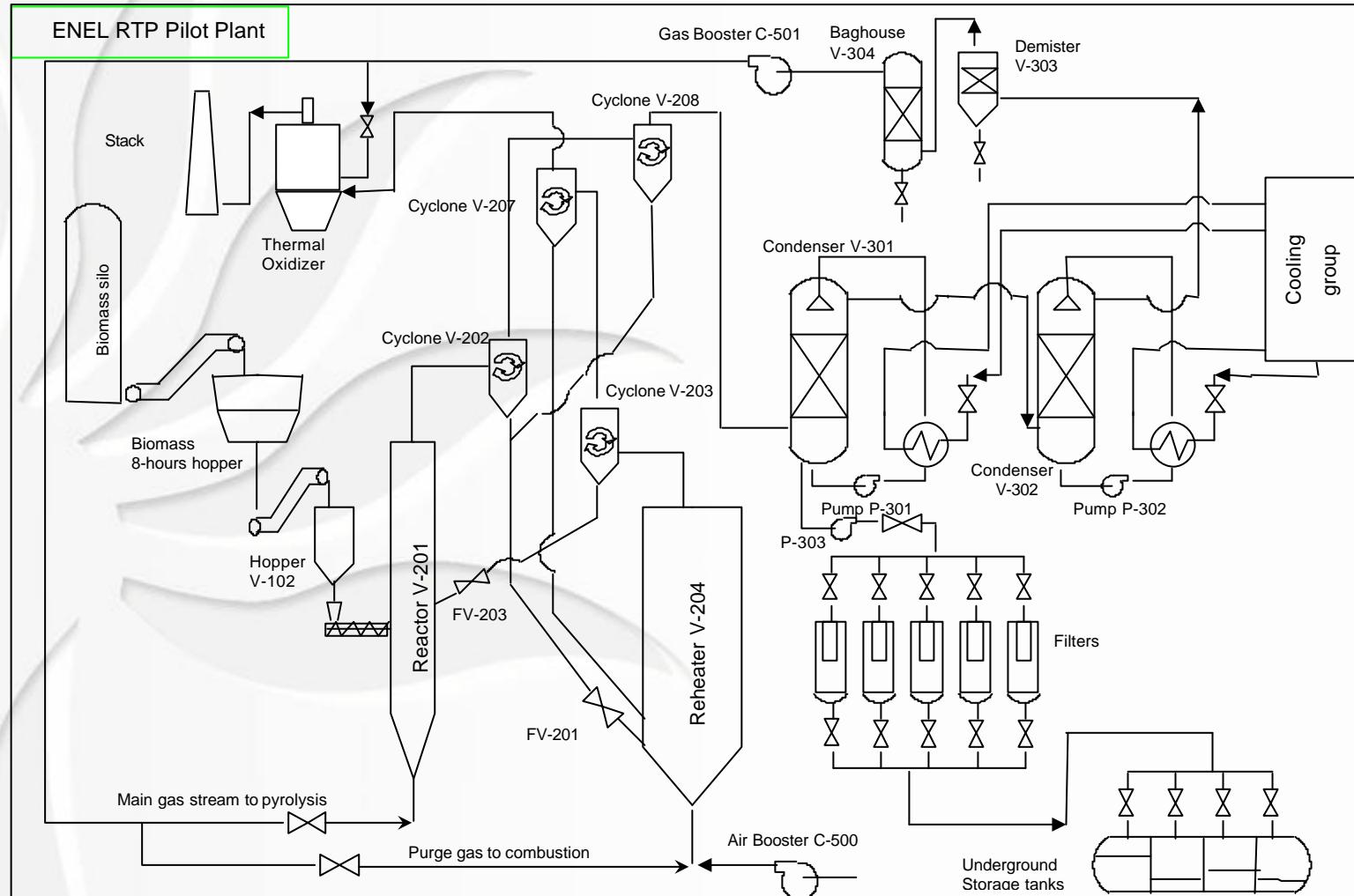
# Fluidized Bed conversion



# Fluidized bed conversion



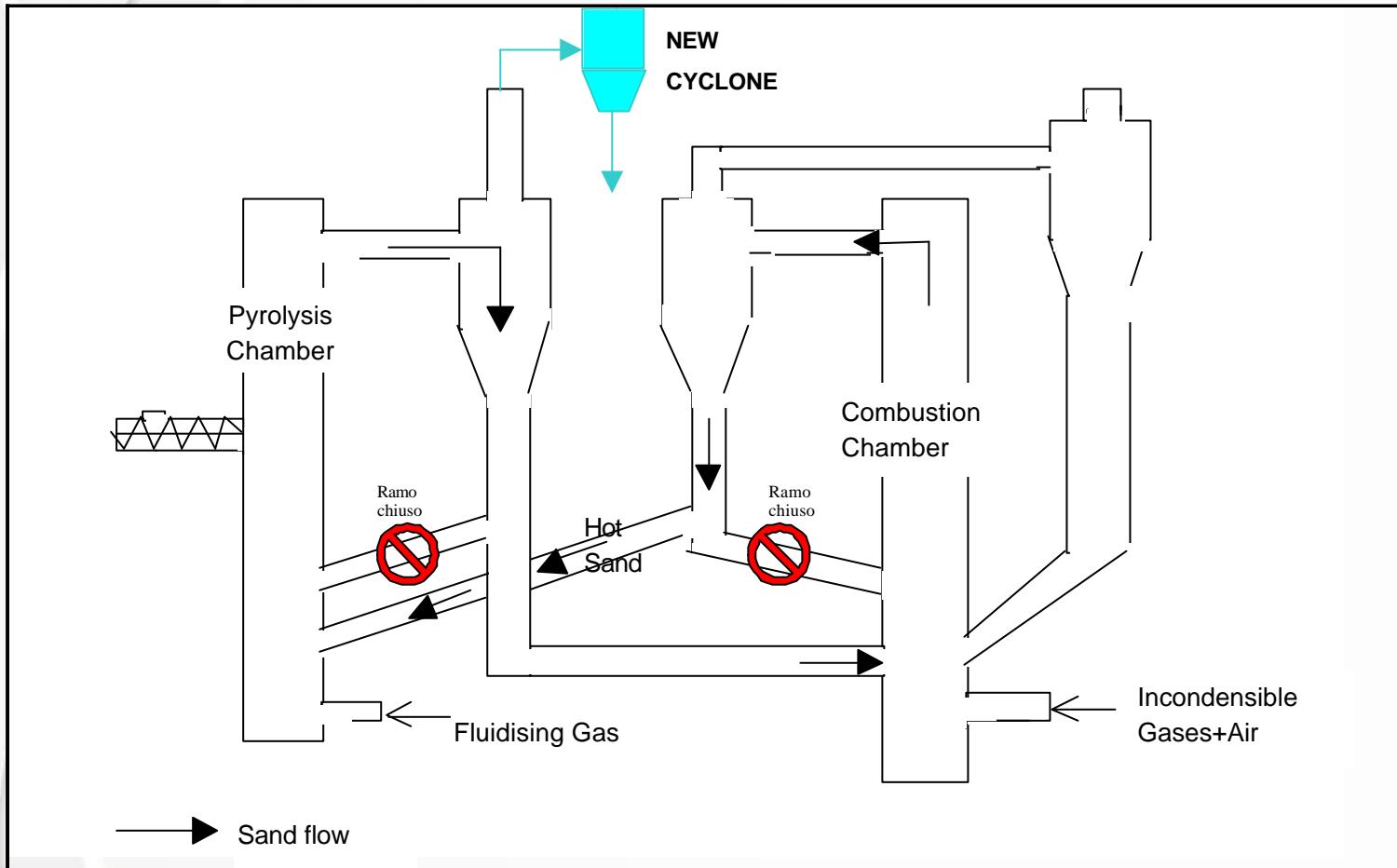
# Flowsheet of the ENEL Plant



(2) Entrained bed



# Fast pyrolysis reactor



# Design conditions of the plant

- Maximum load 625 kg/h sawdust,  $d_{p23} \sim 3$  mm, moisture = 8 %
- Top reactor temperature [500 ÷ 525] °C
- Top reheater temperature ~ 700 °C
- Gas velocity in the reactor [5 ÷ 7] m/s
- Gas velocity in the reheater [5 ÷ 10] m/s
- Rate of solids recircul. [9400 ÷ 18500] kg/h

# Management of the activity

- Need of a step-by-step method, taking into account both the plant size and the problems met during past operation (low plant reliability, low conversion efficiency, limited experience) in order to execute an organic work of process characterization



# Keylines followed in plant modification, improvement and setup

The main items were defined on the basis of past experience and by analysing some key points about the process itself:

- Material balances evaluation
- Conversion efficiency estimation
- Quality of pyrolysis liquid produced
- Plant startup
- Continuous plant operation
- Environmental and hazardous data



# Material Balances + $\eta_{\text{conversion}}$

- **Rate of recirculating syngas**

Two orifice plates for syngas were ordered, installed and their signals acquired and recorded

- **Analysis of recirculating syngas**

A port was placed for spot sampling and analysis of CO ed O<sub>2</sub> into the syngas delivered by C-501 booster

- **Pyrolysis liquid analysis**

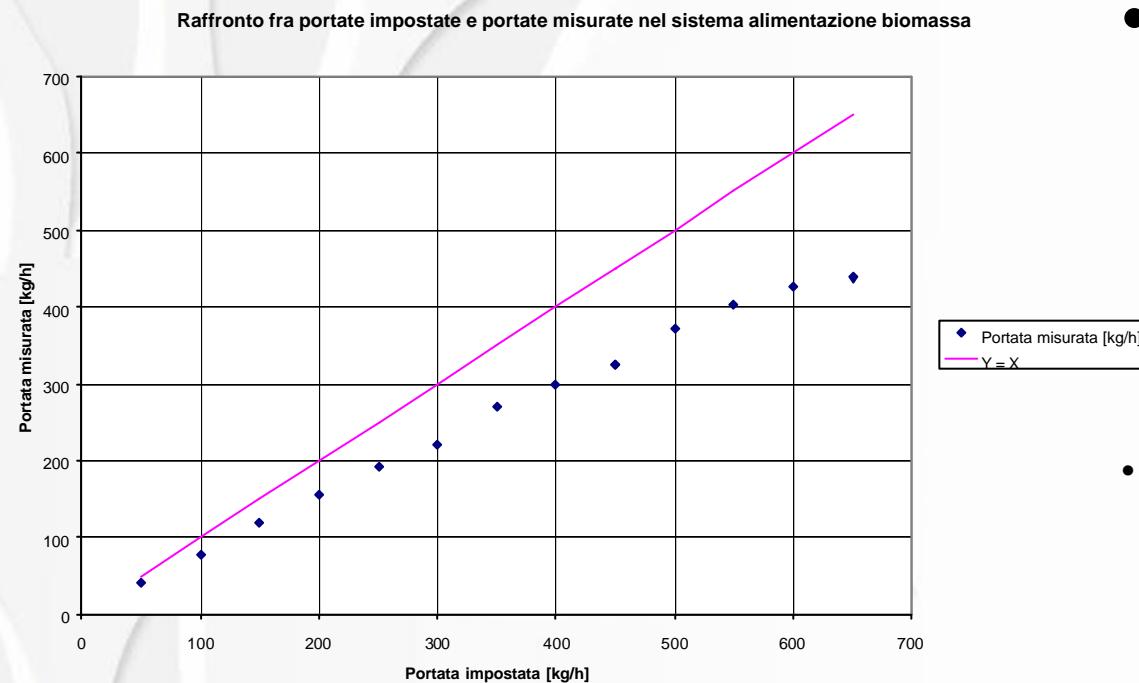
The chemical laboratory of ENEL Produzione will supply the necessary apparatus and chemicals to analyse, directly at the plant, the water contents (according to Karl Fisher method) of the pyrolysis liquid samples that will be taken at suitable times from the temporary settlement tanks

- **Biomass analysis**

The chemical laboratory of ENEL Produzione will supply a thermobalance suitable to test the moisture content of biomass samples, so that such value can be monitored “in real time” while feeding the plant.



# Material Balances + $\eta_{\text{conversion}}$



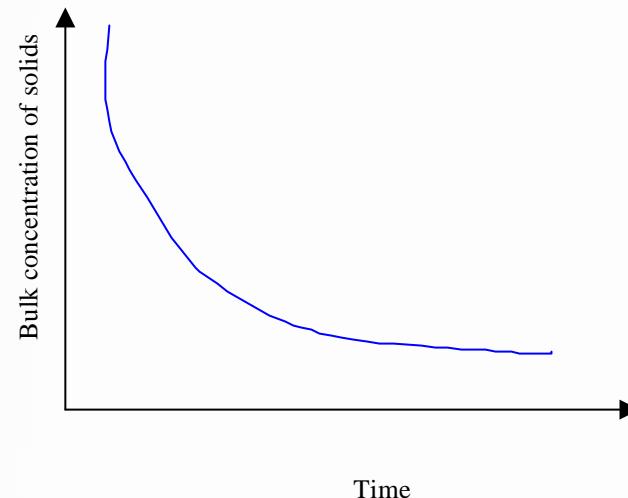
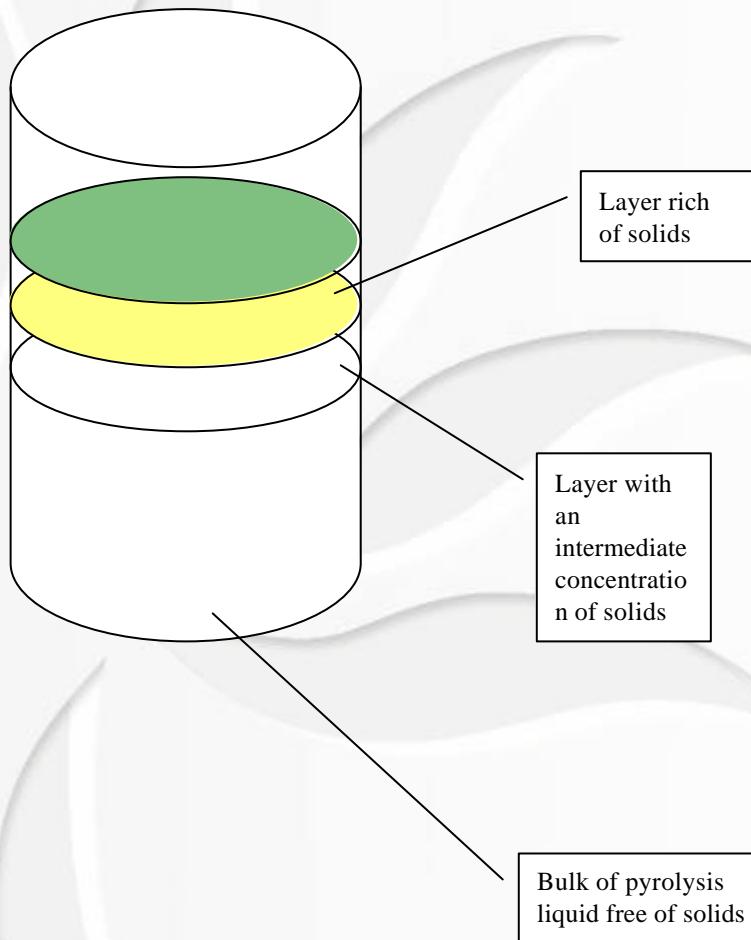
- Experimental calibration of biomass rate measuring system
- All over the range of flowrates that can be selected by the control system, biomass was feeded for a measured time interval, than the discharged sawdust was collected and weighed. The graph obtained was used to update the control system.

# Quality of pyrolysis liquid

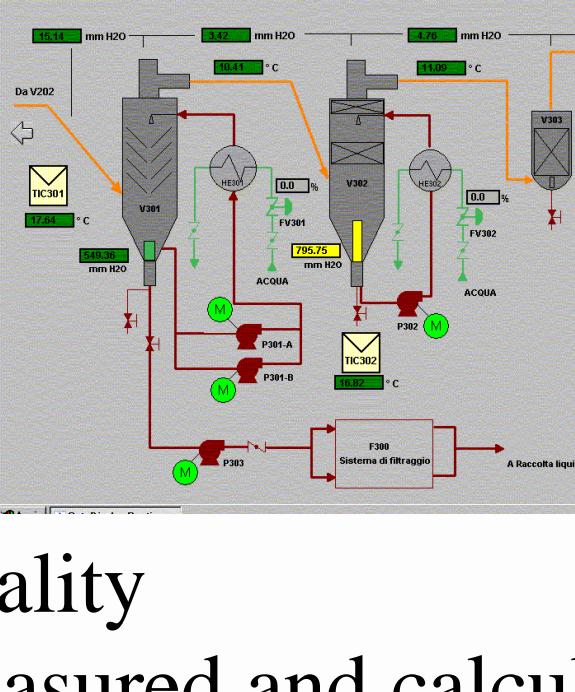
- Solids capture from the pyrolysis [gas+vapour] mixture
- Selection and installation of temporary settlement tanks
- Control of solids recirculation
- Temperature control

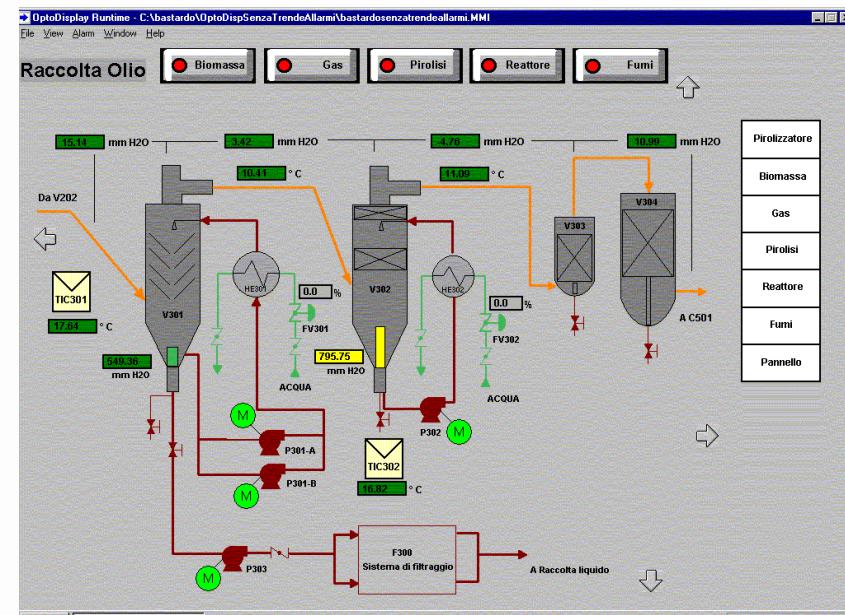


# Temporary settlement tanks for P.L.



# Material Balances + startup and operation

- A new control system (Opto 22) was installed, compatible with the Opto bricks existing on the plant
  - Check of system functionality
  - Archives to record the measured and calculated variables read by the control system



# Startup and operation - selection of bag material for Filter V-304 - Resistance test to pyrolysis liquid



SCHEDA TECNICA		ARTICOLO	PC-PP-530.021	ozella
	CODICE	PC-PP		
	APPLICAZIONI	FILTRAZIONE		
Descrizione:				Panno agguato in Poliestere con tessuto bocca in Poliestere Wet Polyester Hull with Polyester Screen
U.M.				Nome DB
Riciclaggio a Rotolo Textile Recycling				
Longitudinale	mt	1400		52857
Length				
Transversale	mt	1200		52857
Cross				
Allungamento a Rotolo Elongation at Break				
Longitudinale	%	10		52857
Length				
Transversale	%	18		52857
Cross				
Peso Weight	g/m <sup>2</sup>	500		52854
Spattare Thickness	mm	2,1		52855
Porousità a fissa Air Permeability				
Mtr <sup>2</sup> /Min a 200 Pa		200		52857
Resistenza a la Temperatura Temperature Resistance				
- Continua	°C	140		
- Cott.				
- Poco	°C	150		
Point				
Stabilità dimensionale a 140 °C - % Max. Change of Dimensions at 140 °C				<1
Trattamento Superficiale Surface Treatment				
Bordura Design/Motif	Type	Termodiabolo		
	Type	Hot Water		
		Boil Wash		
		Stirred Face Side		
I dati riportati sono soltanto indicativi e possono essere soggetti a modifica applicando le usuali tolleranze.				
The above mentioned data is indicative. Moral tolerances and technical modifications are kept in reserve.				



# Preliminary calculations -

## maximum reheater load

- Reheater dimensions:  
 $D_i = 0.356 \text{ m}$ ;  $H = 6.1 \text{ m}$
- Maximum air flowrate from C-500 blower:  
 $0.236 \text{ Nm}^3/\text{s}$  [14000 litri/min]
- With a 4 %  $O_2$  in the flue gas from the reheater, and under the hypothesis of only burning the biomass char, the maximum load of the plant would be 420 kg/h sawdust.



# Preliminary calculations -

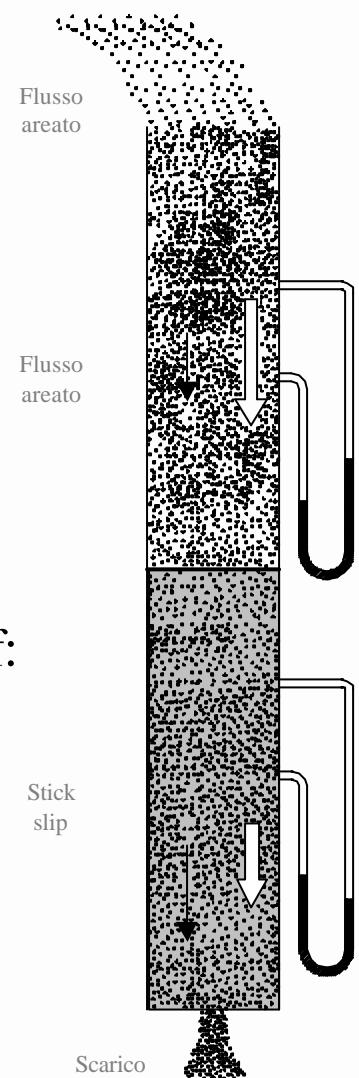
## Recirculation of solids

- Minimum sand rate of  $\approx 7300 \text{ kg/h}$  (from thermal balance)
  - ↑ entrained flow in the reactor and reheater
  - ↖ “stick slip” flow into the loop seals
- Solids flowing in the loop seal ducts undergo entrainment if:

$$P_{downstream} - P_{upstream} > r_{gas\_solids\_mixture} g \Delta h$$

If  $\Delta p \approx$  second term, the flow is “aerated”

If  $\Delta p <$  second term, the flow is “stick slip” (just a fixed bed moving downwards)



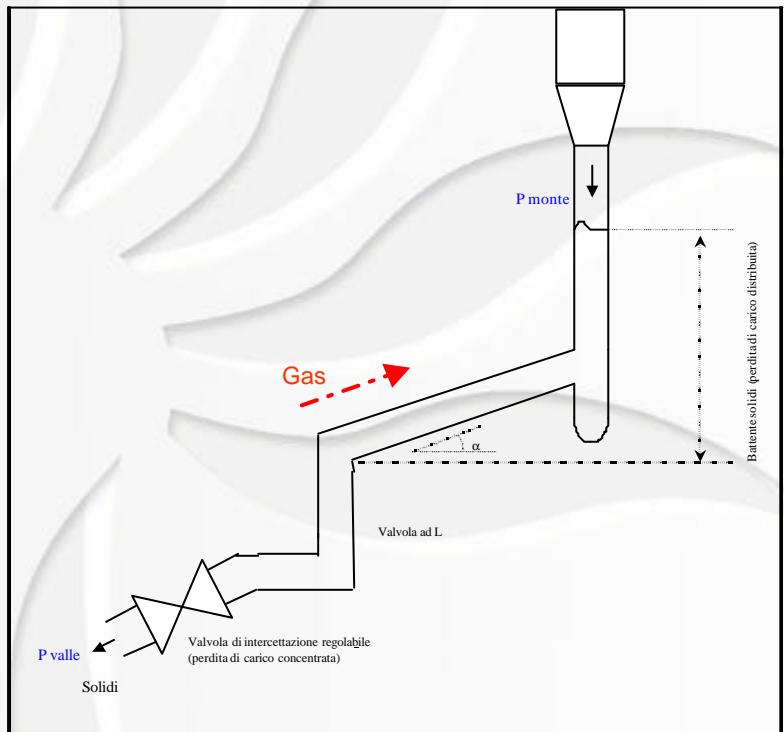
# Total solids load from past operation data

$$Mass_{bed} \approx \frac{\Delta p A}{g} = [r_g e + r_s (1-e)] Ah$$

	Deltap recorded [kPa]	Calculated load of solids in = DeltaP*A/g [kg]
Minimum upon reactor	7	35
Maximum upon reactor [kPa]	13	65
Minimum upon reheater [kPa]	16	173
Maximum upon reheater [kPa]	16	173



# Preliminary calculations: solid load into the loop seals



- Sand  $d_{p23} = 150 \mu\text{m}$ : a situation in which sealing is effective can be found
- Sand  $d_{p23} = 450 \mu\text{m}$  complete sealing is much more difficult, and corresponding to unfavourable conditions of solids level and valve

# Preliminary calculations: residence times into the risers

At the gas flowrates and temperatures of interest:

- gas residence times in the reactor < 1.5 sec.
- gas residence times in the reheater < 1 sec.
- Sand residence times in the upper part of the reactor < 2 sec (based on transport velocity of a single particle)
- Biomass residence times in the upper part of the reactor < 1 sec (based on transport velocity of a single particle)

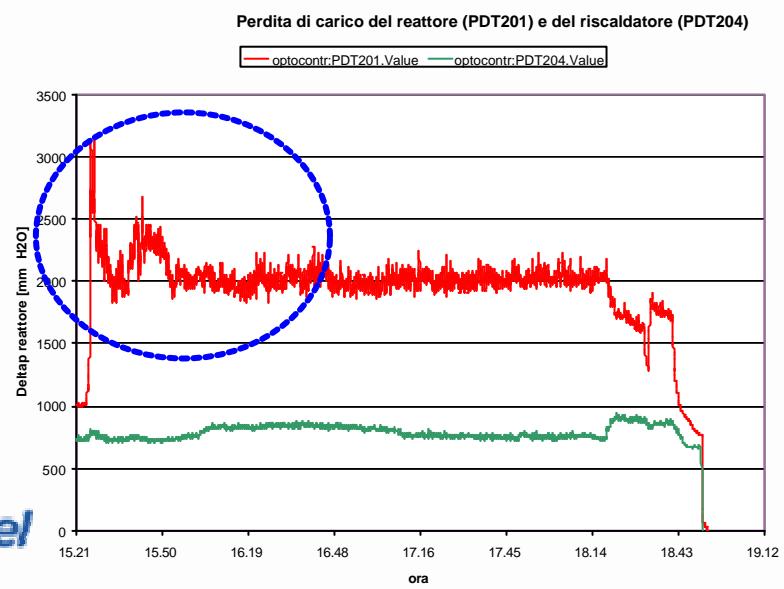
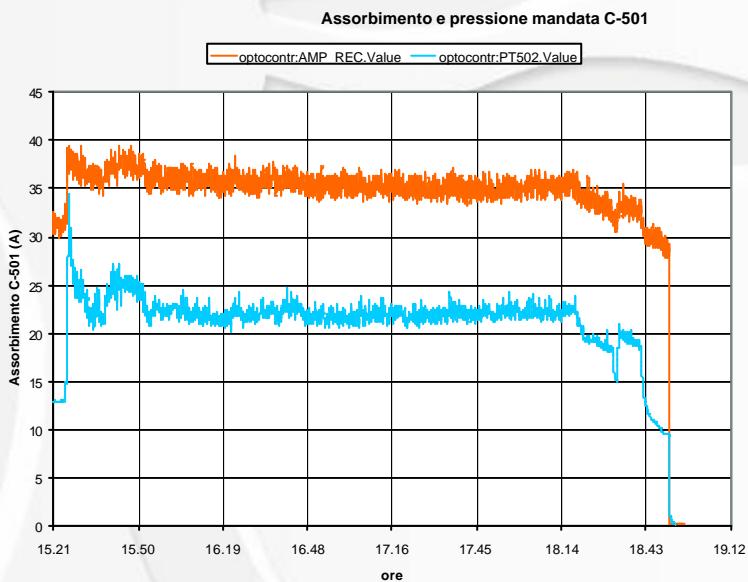
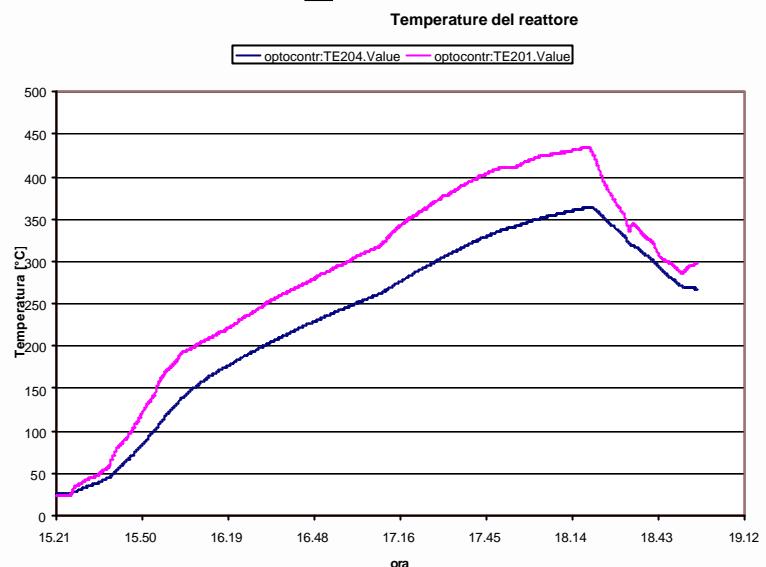
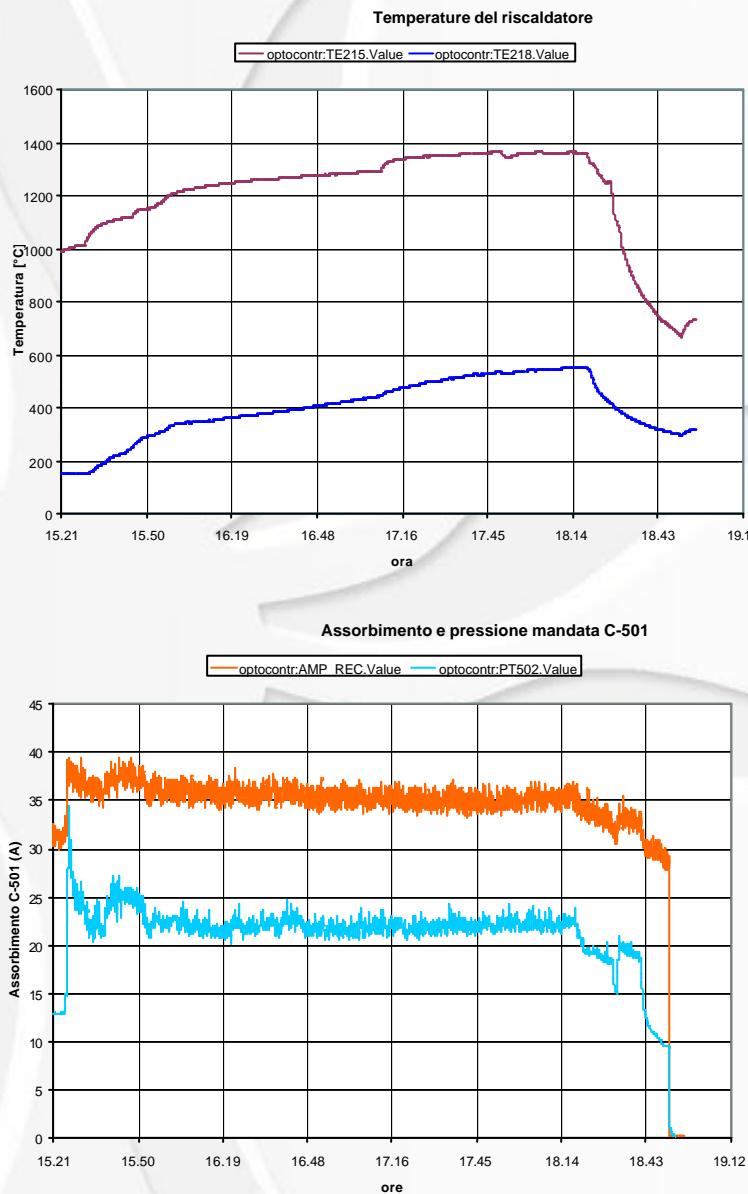


# First tests - critical points

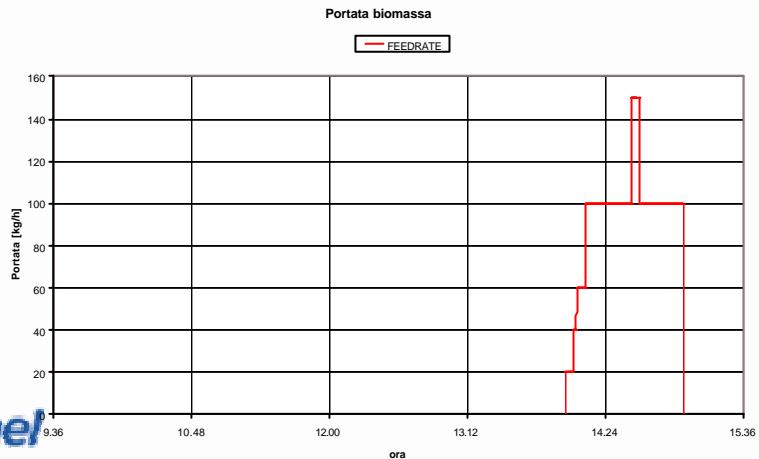
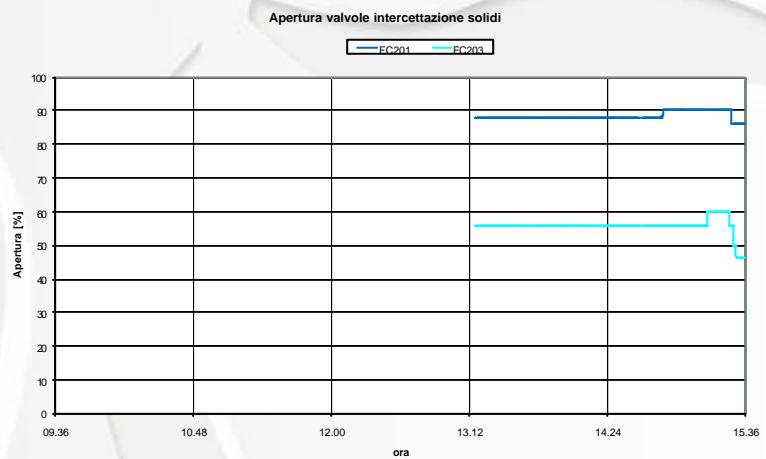
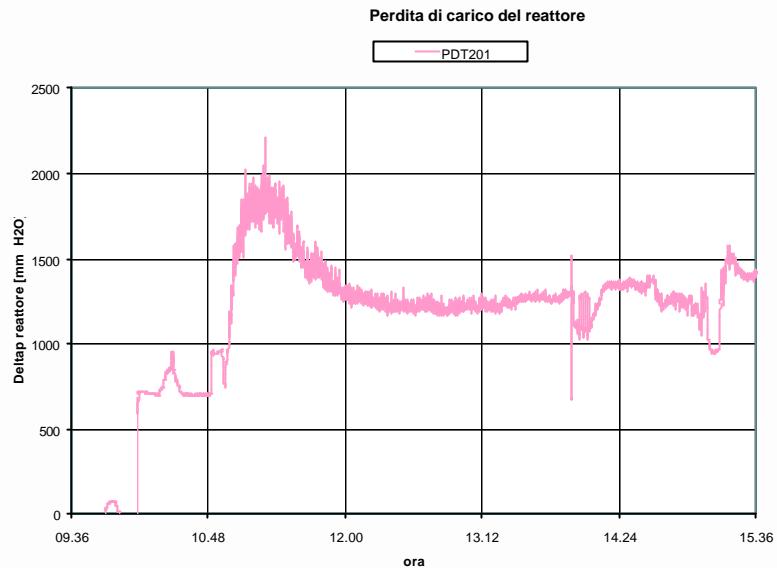
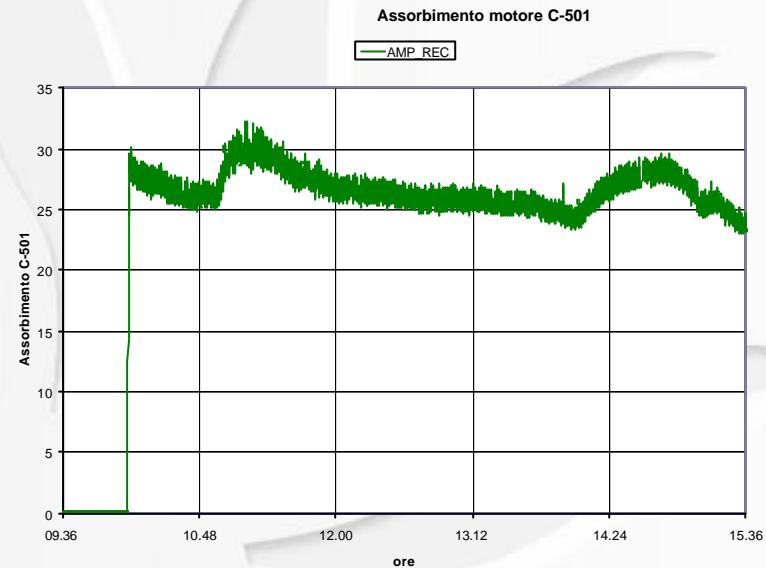
- Formation and entrainment of foams to the gas cleanup section of the plant
- calibration of fluidizing gas inlets to loop-seals
- air bypass along the standpipe of cyclone V-207
- firing of the pilot burner
- load of the main burner
- power of C-501blower's engine
- biomass feeding system



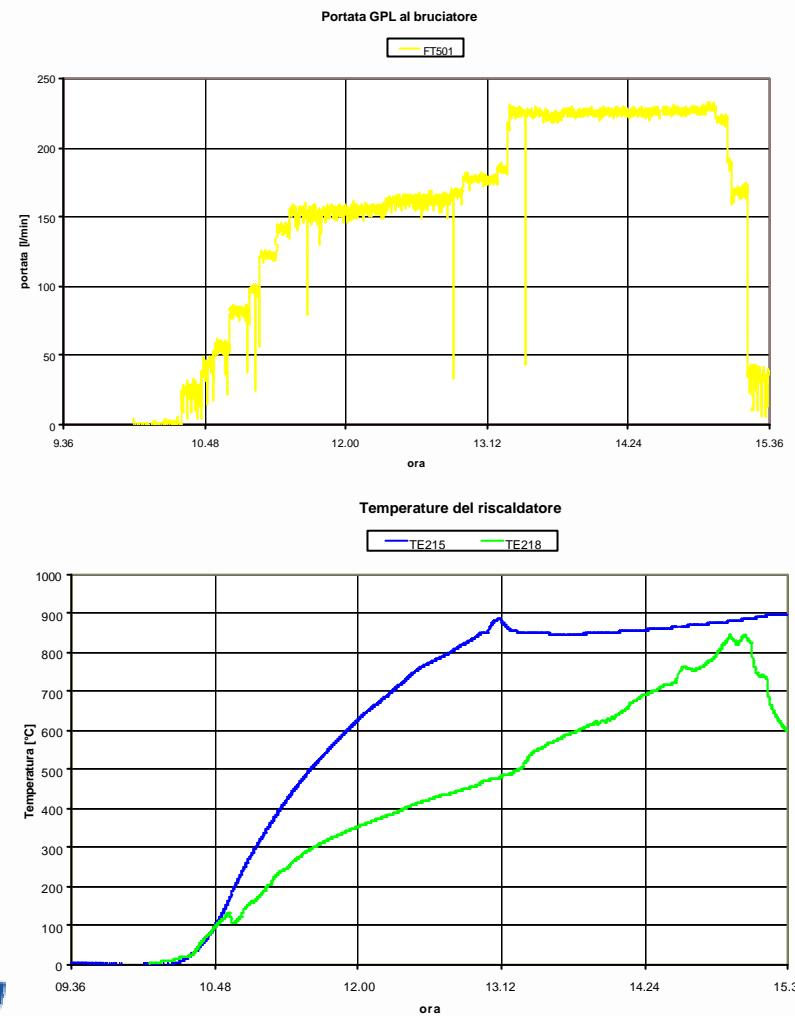
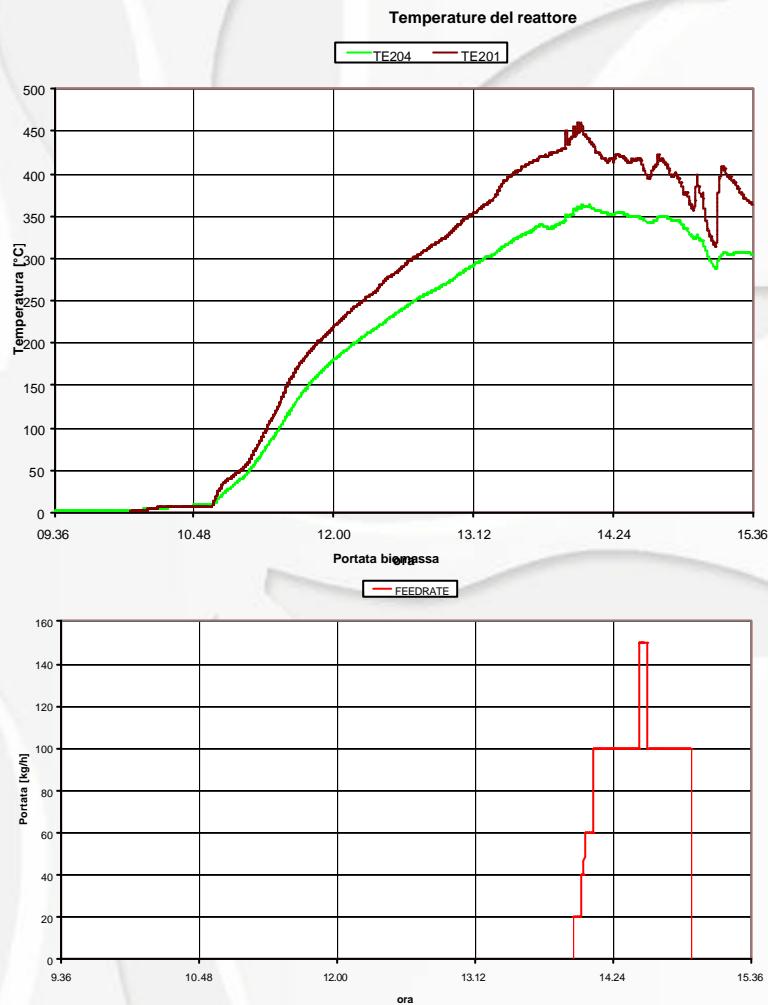
# Ex. 1 - plant heatup



# Ex. 2 - heat up and pyrolysis (1)



# Ex. 2 - heat up and pyrolysis (2)



# To be observed: effects of fine solids

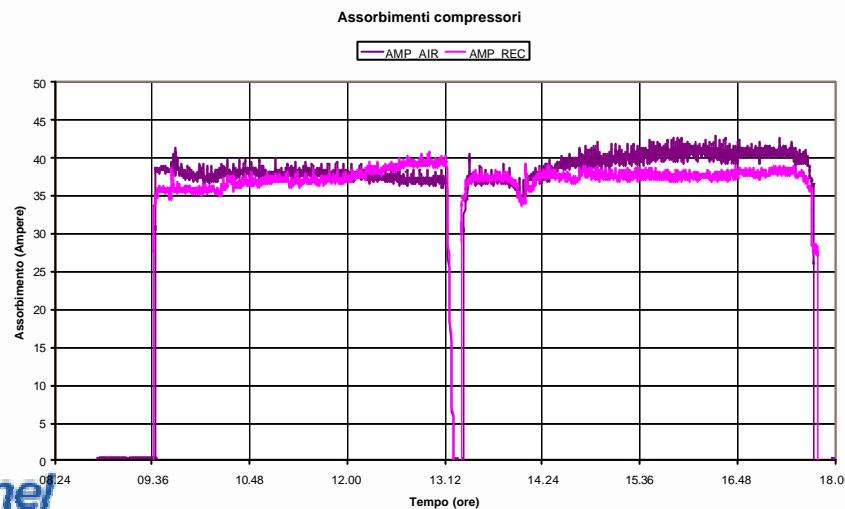
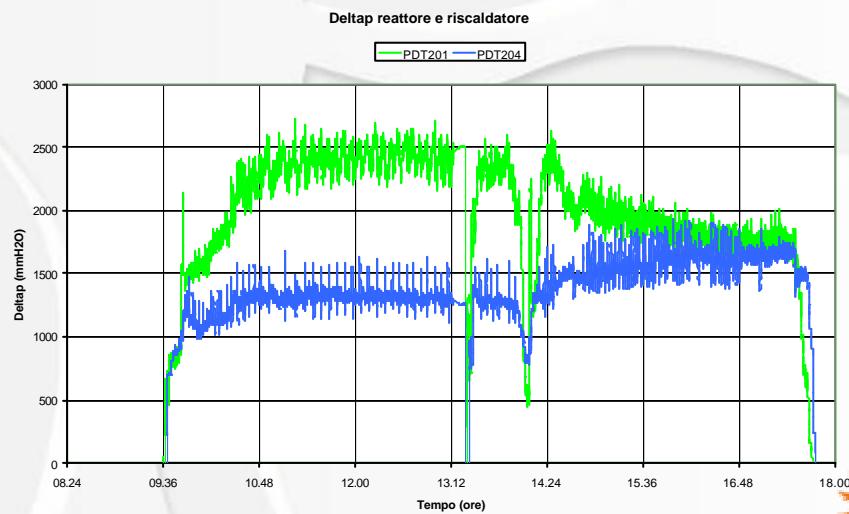
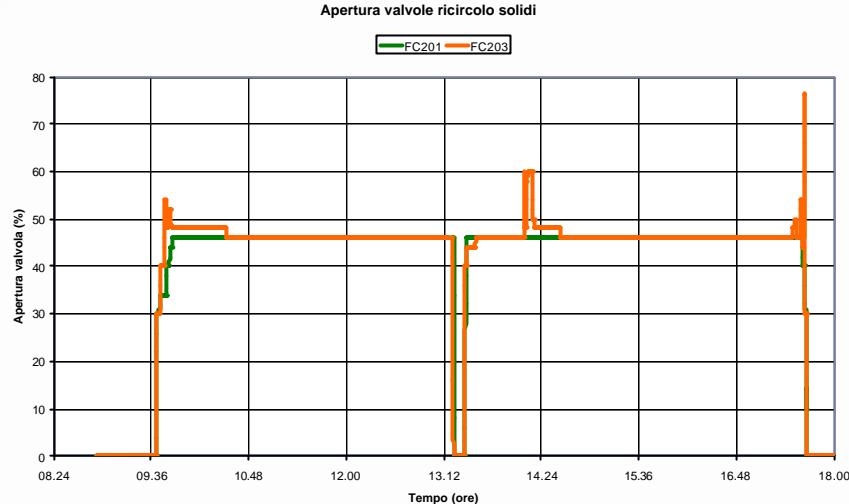
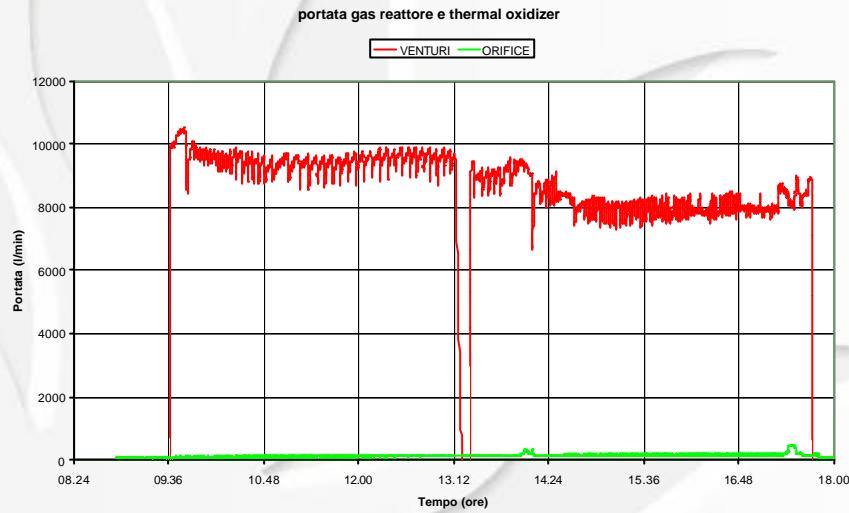


# Further Modifications

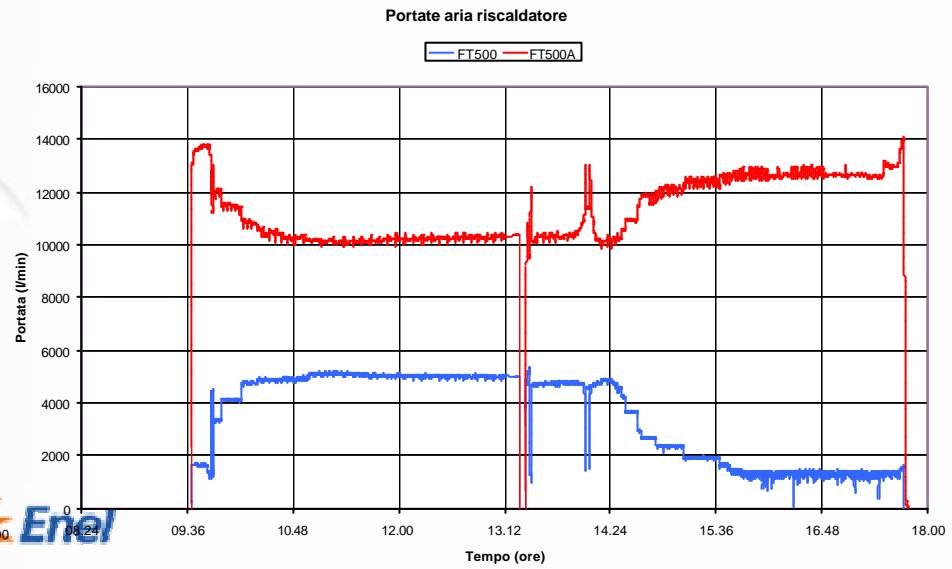
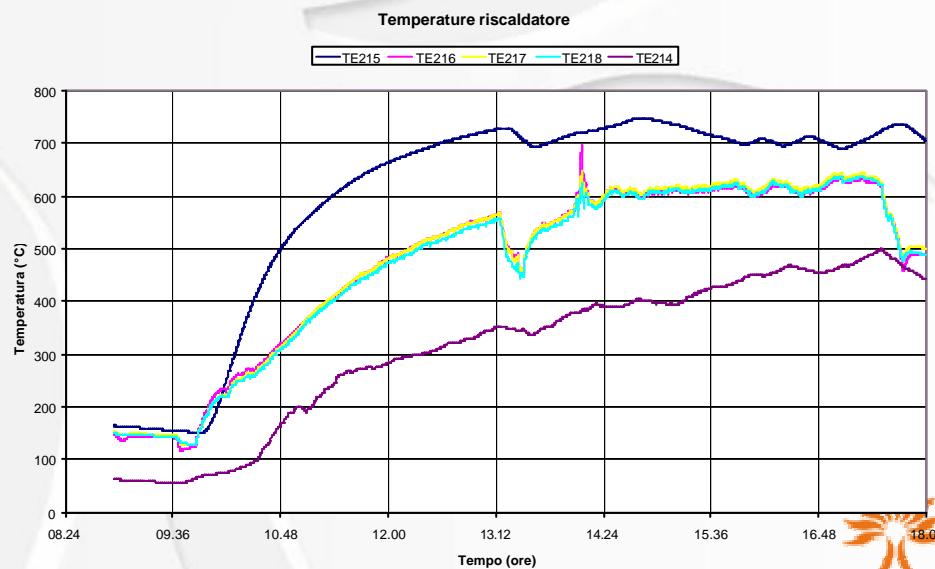
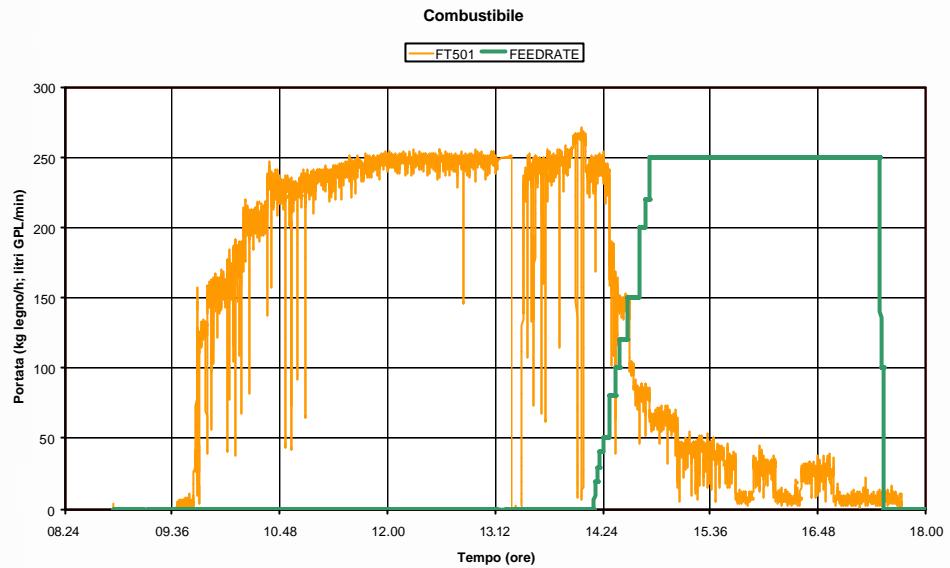
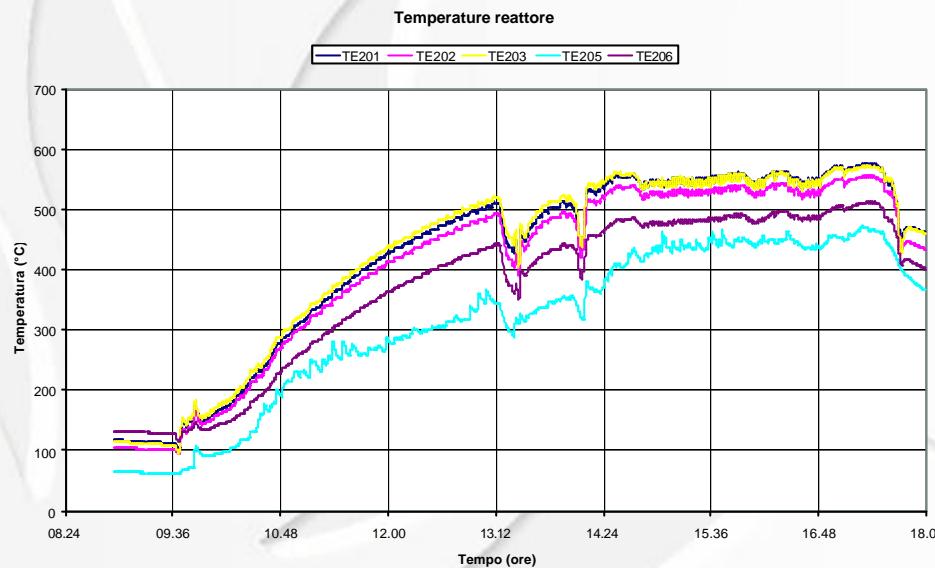
- Replacement of the engine of gas booster
- Loop seal for reactor's second cyclone
- Control of the air rate and of the pressure at the reheater's bottom (via a recycle valve on the air booster)
- Larger bypass of the baghouse



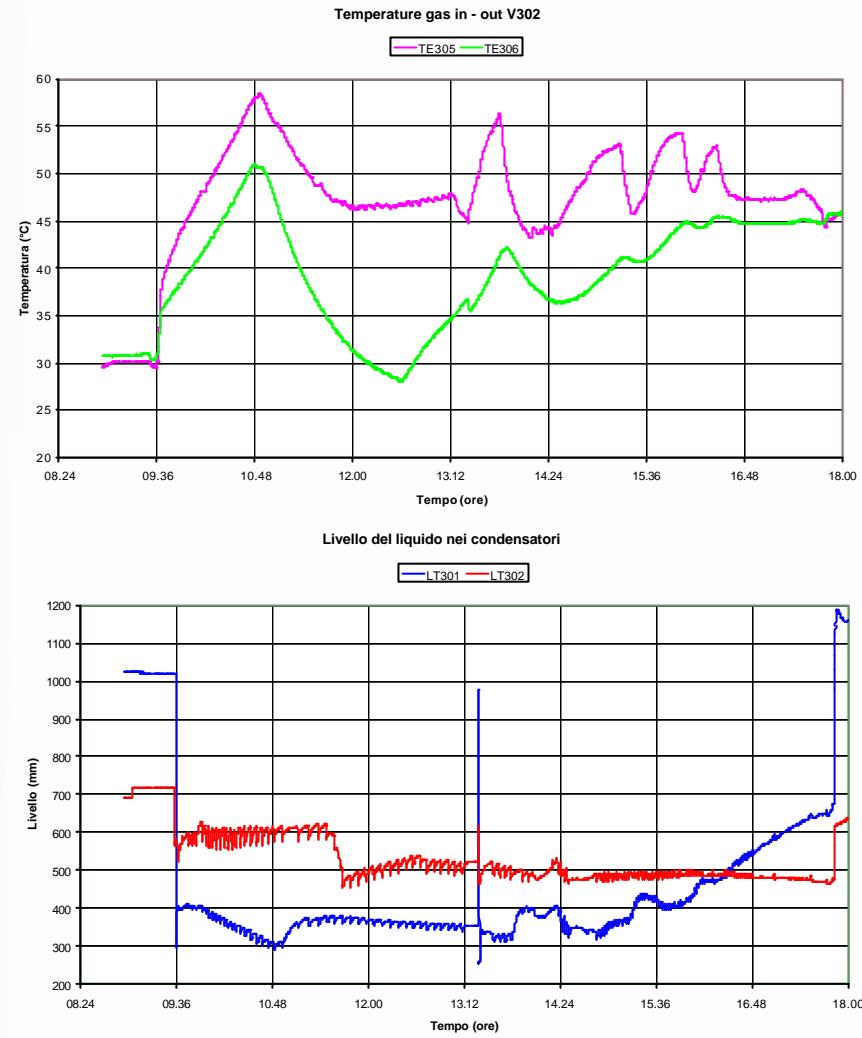
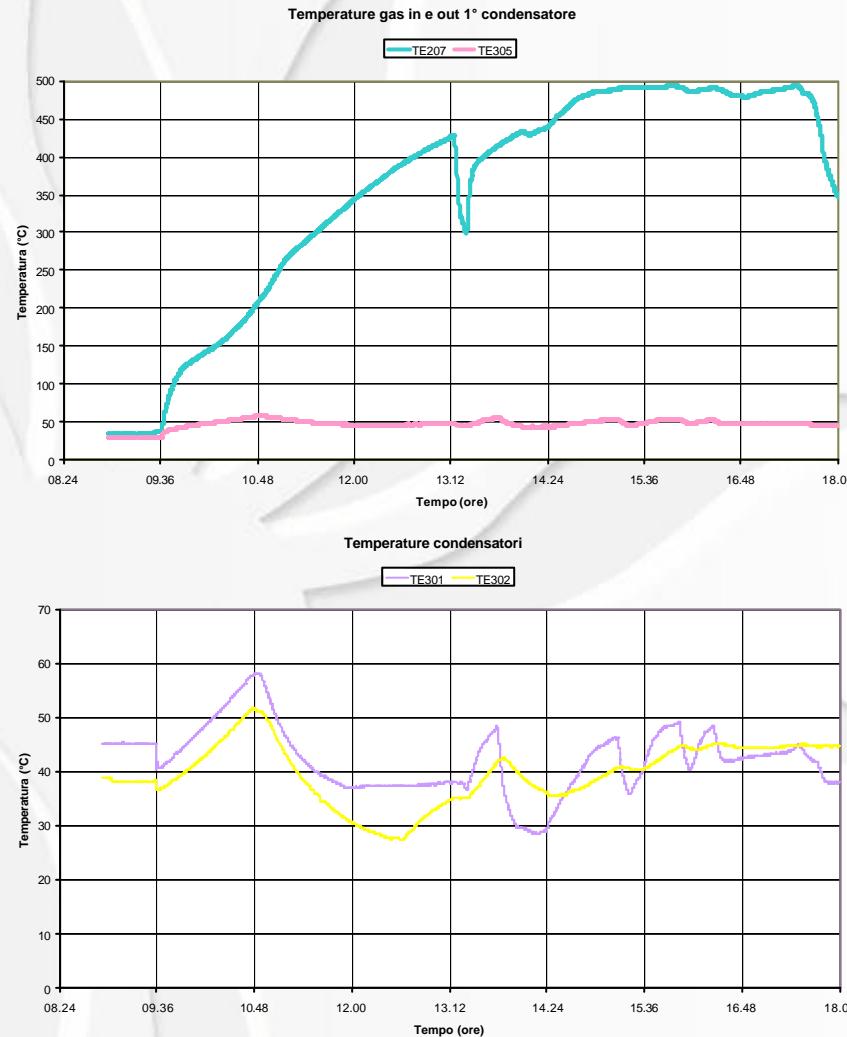
# Test example at present conditions (1)



# Test example at present conditions (2)



# Test example at present conditions (3)



# Test example at present conditions (4)

